

3D Rotational Angiography: Recent Experience in the Evaluation of Cerebral Aneurysms for Treatment

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Summary

Three dimensional (3D) reconstruction techniques providing volume rendered 3D images from rotational angiography data now exist. We report the design and early experience with one such system. 237 aneurysms were studied. Information was obtained on the morphology of the aneurysm itself and the vascular architecture in and around the aneurysm. 218 (92%) aneurysms went on to have endovascular treatment.

The 3D images provided valuable information on aneurysmal anatomy, including relationships with the parent and adjacent vessels. This technique allowed fast and safe decision-making regarding the feasibility of endovascular or surgical treatment and provided useful information for performing the chosen treatment.

Introduction

Despite recent technical innovations, including contrast enhanced, high resolution computed tomography (CT) and magnetic resonance angiography (MRA), digital subtraction angiography (DSA) is still considered to be the "gold standard" for the study of cerebral aneurysms. Biplane DSA, with multiple projections, is an efficient technique.

Unfortunately, however, it does not always

afford a complete understanding of complex vascular anatomy and may fail to show the neck of an aneurysm.

In this article, we present a system that provides volume-rendered 3D reconstructed images of vascular anatomy from one non-subtracted rotational angiography run. The images have excellent resolution, and can be rotated on the workstation screen to obtain any desired projection, providing views that are often not obtainable using conventional angiography.

This technique also allows the neurosurgeon to simulate the view of the aneurysm to be expected in the surgical approach and enables the interventionist to choose the best projection for an endovascular procedure.

Equipments and Methods

The images used for 3D reconstructions were acquired on a standard Integris BV5000 biplane system (Philips Medical Systems, Best, Netherlands) using Rotational Angiography. With this technique, a series of images is obtained while the C-arm rotates in a continuous movement around the region of interest.

The acquisitions can be made in the axial plane, or in a plane with 30° cranial or 30° caudal angulation. These angulations allow the

user to choose the projection that best matches the orientation of the object and avoids superimposed structures.

Calibration

The images used for the 3D reconstruction need to be corrected for the usual distortions caused by the Image Intensifier. The correction factors are calculated from calibration exposures. These are Rotational Angiography exposures obtained with dedicated calibration phantoms for each of the three available angulations. However, the user sees nothing of this. The calibration is performed in advance by a service engineer, and the corrections are applied to the images completely automatically. It is essential that the calibration and clinical images match precisely. As calibration and clinical acquisitions are made at different moments in time, this requires an extremely stable and reproducible geometry.

In our case, this requirement is met by the precisely engineered counterbalanced C-arm of the system. Regular checks have shown that the calibration stays valid for at least six months.

Acquisition

Images are acquired in the rotational angiography mode over an angle of 180°. The run may be performed in one of three different angulations of the C-arm: -30° cranial, 0° axial, or +30° caudal, depending on the orientation of the object of interest. Images are acquired at a low dose level, with a frame rate of 12.5 frames per second, and a rotation speed of up to 30° per second. Allowing for the C-arm coming up to speed at the beginning of the run and reducing speed at the end, the whole acquisition takes eight seconds, resulting in an average of 100 images per run. During the run, 300 mg/ml iodinated contrast agent is injected at a flow rate of 4 to 5 ml/s, providing continuous filling of the vasculature.

Reconstruction

After acquisition, the 100 contrast-enhanced images are transferred to the workstation. During transfer, all images are automatically corrected, and a predefined default volume is au-

tomatically reconstructed around the isocenter of rotation using a modified filtered backprojection cone-beam algorithm. This initial reconstructed volume can be viewed interactively, with real-time volume rendering. This allows the vessel morphology to be viewed in any direction. The visibility of the vessel structures can be enhanced by adjusting the window levels. Cut planes can be displayed at any arbitrary position in the volume, cutting off part of the reconstructed cube. This allows further inspection, providing cross sections of the aneurysm and/or parent vessels and eliminating superimposed structures.

The initial reconstructed volume covers the complete imaged vessel tree, and serves as a roadmap for other reconstructions. This offers the possibility of making user-defined reconstructions in different areas, with free selection of location, size and reconstruction matrix. This technique, referred to as reconstructive zooming, applies the full reconstruction matrix to the real region of interest, thus enhancing the resolution and providing the maximum possible detail.

The default reconstruction procedure, from acquisition to the first 3D volume, takes approximately six minutes. A reconstructive zoom can vary from 15 seconds to 10 minutes, depending on the number of voxels in the volume. Tests with a phantom show that the reconstructions are very accurate.

A comparison of the size of the different dimensions, measured in the orthogonal planes of the reconstruction, deviates from the actual size by less than 2%.

Results and Experience

Between February 1998 and February 1999, 237 aneurysms were studied by 3D rotational angiography at our center. Of these, 218 (92%) went on to have endovascular treatment. In most cases, the studies provided useful spatial, anatomical information required for treatment, be it endovascular or surgical. The best image projection of the aneurysm for coil embolisation was easily obtained by rotating the 3D image on the computer workstation screen with a mouse.

Three patient axes displayed simultaneously on the screen of the workstation, along with angles of the image intensifier C-arms required to

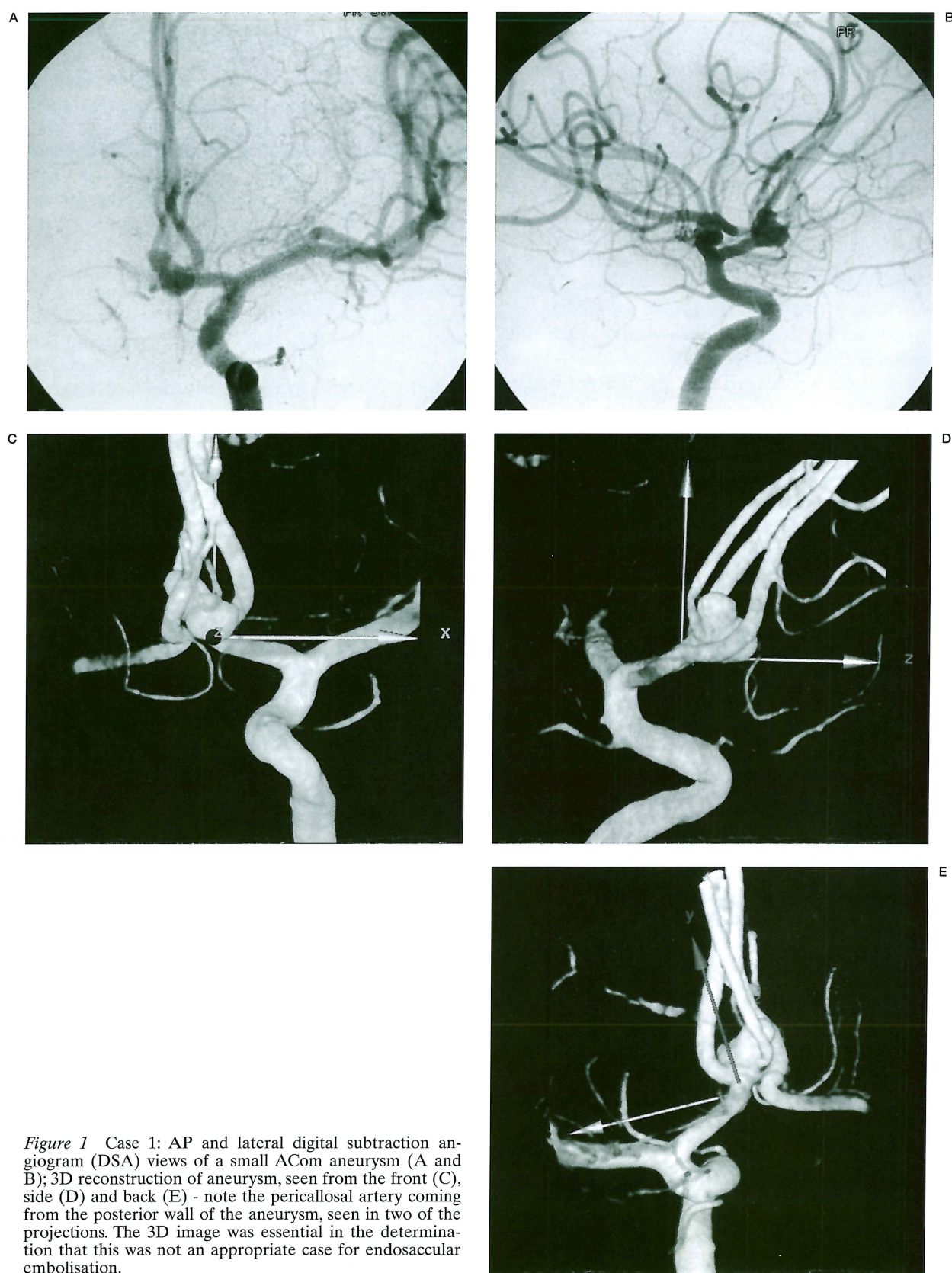


Figure 1 Case 1: AP and lateral digital subtraction angiogram (DSA) views of a small ACom aneurysm (A and B); 3D reconstruction of aneurysm, seen from the front (C), side (D) and back (E) - note the pericallosal artery coming from the posterior wall of the aneurysm, seen in two of the projections. The 3D image was essential in the determination that this was not an appropriate case for endosaccular embolisation.

obtain this view, made this a straightforward procedure.

The 3D views allowed for accurate assessment of aneurysm morphology and neck size, as well as complex anatomical relationships with parent and adjacent vessels. These images allowed for accurate and safe decision-making regarding the feasibility of endovascular treatment, or indeed if treatment was necessary at all. For instance, one patient who had suffered a small subarachnoid haemorrhage and was considered to harbor an anterior communicating artery (ACoM) aneurysm on DSA, was shown on 3D angio to have simply a tortuous vessel in the ACoM area. A follow-up study two weeks later confirmed that the patient had no aneurysm.

In those cases not suitable for embolisation, the images often proved useful for the neurosurgeon, especially in terms of the anatomy of adjacent branches. The angle of a surgical approach could easily be recreated simply by rotating the 3D image of the aneurysm in order to simulate the procedure preoperatively.

In addition to the pretreatment information, 3D rotational angiography turned out to be very useful for evaluation of the neck of aneurysm, and the remnant space after the treatment. No distortion, or artifacts were in any of the images of vessels with metallic implants, including coils, clips and stents.

Illustrative Cases

Case 1: useful 3D information for interventionist and surgeon (figure 1)

A 41-year-old woman was referred for consideration for endovascular treatment by a neurosurgeon after an MRI performed for evaluation of a prolactinoma revealed the presence of a small ACoM aneurysm. The 3D study, however, revealed that a pericallosal artery came directly off the posterior wall of the aneurysm. It was felt that it would be impossible to protect this vessel during endosaccular coiling.

The anatomical relationship of this vessel to the aneurysm, on the wall, was important information for the surgeon contemplating surgery. While the aneurysm was felt to be clippable, and an operation was recommended, the patient elected to defer surgery.

Case 2: useful 3D information for the interventionist - to rule out coiling (figure 2)

This 55-year-old woman presented with a history of depression and some memory loss. As part of her work-up she underwent MR imaging that revealed a moderate-sized right middle cerebral artery (MCA) aneurysm. She was referred, again by a neurosurgeon, for an opinion regarding the feasibility of an endovascular procedure. The 3D study showed a wide-necked MCA bifurcation aneurysm, with the proximal aspect of both M2s being intimately associated with the aneurysm. Given the likelihood that the GDC coils would impinge on the origin of the M2s, and that balloon protection of both of these branches was not possible, an endovascular approach was not recommended. The patient also elected to have her aneurysm treated by her neurosurgeon.

The information obtained for the 3D study in this case was essential for the determination that this aneurysm could not be treated endovascularly. As MCA aneurysms are usually easy to expose, it could be argued that the study did not add much from a surgical point of view. The quality of images such as these, however, might provide an increased level of comfort for the neurosurgeon about to undertake a procedure on this aneurysm. The amount of detail is illustrated by the fact that a very small incidental aneurysm on the feeding M1 vessel, which was not well appreciated on the conventional DSA images, was seen very clearly on the 3D reconstruction.

Case 3: useful 3D information for the interventionist - determination of treatment strategy (figure 3)

A large basilar bifurcation aneurysm was discovered at angiography in a 43-year-old woman who had suffered a Hunt and Hess Grade IV subarachnoid haemorrhage. She also harbored a small P2 posterior cerebral artery (PCA) aneurysm on the right side as well as very small right MCA and pericallosal aneurysms. The CT scan indicated that it was almost certainly the basilar lesion that had bled. The patient's clinical condition improved. An attempt at embolisation of this large aneurysm was made one week after initial presentation, at another center. Satisfactory coil position could not be obtained, however, as the left P1 always ended up

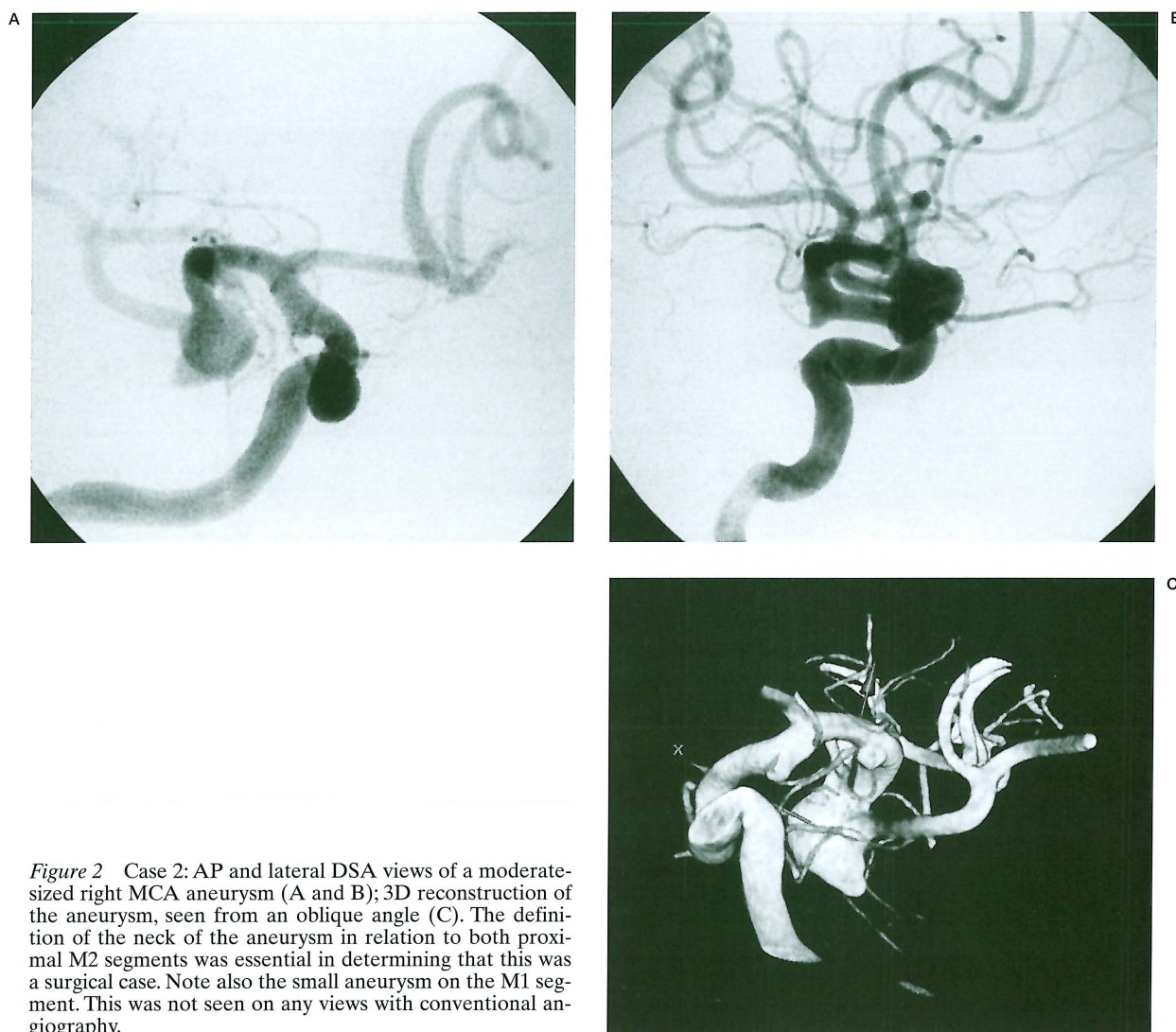


Figure 2 Case 2: AP and lateral DSA views of a moderate-sized right MCA aneurysm (A and B); 3D reconstruction of the aneurysm, seen from an oblique angle (C). The definition of the neck of the aneurysm in relation to both proximal M2 segments was essential in determining that this was a surgical case. Note also the small aneurysm on the M1 segment. This was not seen on any views with conventional angiography.

being compromised by the coils. She was referred to our center and underwent evaluation and treatment three weeks after her bleed.

The 3D study showed that the neck was broad, encompassing both P1 segments, most especially the left. Given the anatomical relationships, and the fact that the patient had a good posterior communicating artery (PCom) on the right side, it was decided that the best approach to protect both proximal P1 vessels was to deploy a remodelling balloon across the base of the aneurysm, bridging across the base of the aneurysm from one P1 to the other, after access via the internal carotid artery (ICA) and PCom.

The procedure was well tolerated and without complications. A 3D study at the end of the

procedure showed the cast of GDC coils that had been "remodelled" by the balloon. The information obtained from the 3D study was useful in determining the need for a remodelling balloon and in choosing the angle of attack to use for its deployment. It should also be useful for monitoring any deformation of the material in the course of follow-up.

Discussion

There is room for improvement in the imaging of cerebral aneurysms. Conventional angiography fails to identify a structural cause for bleeding in 2%-27% of patients after subarachnoid haemorrhage^{2,8,11,17}. Aneurysms may be missed because of poor image resolution or in-

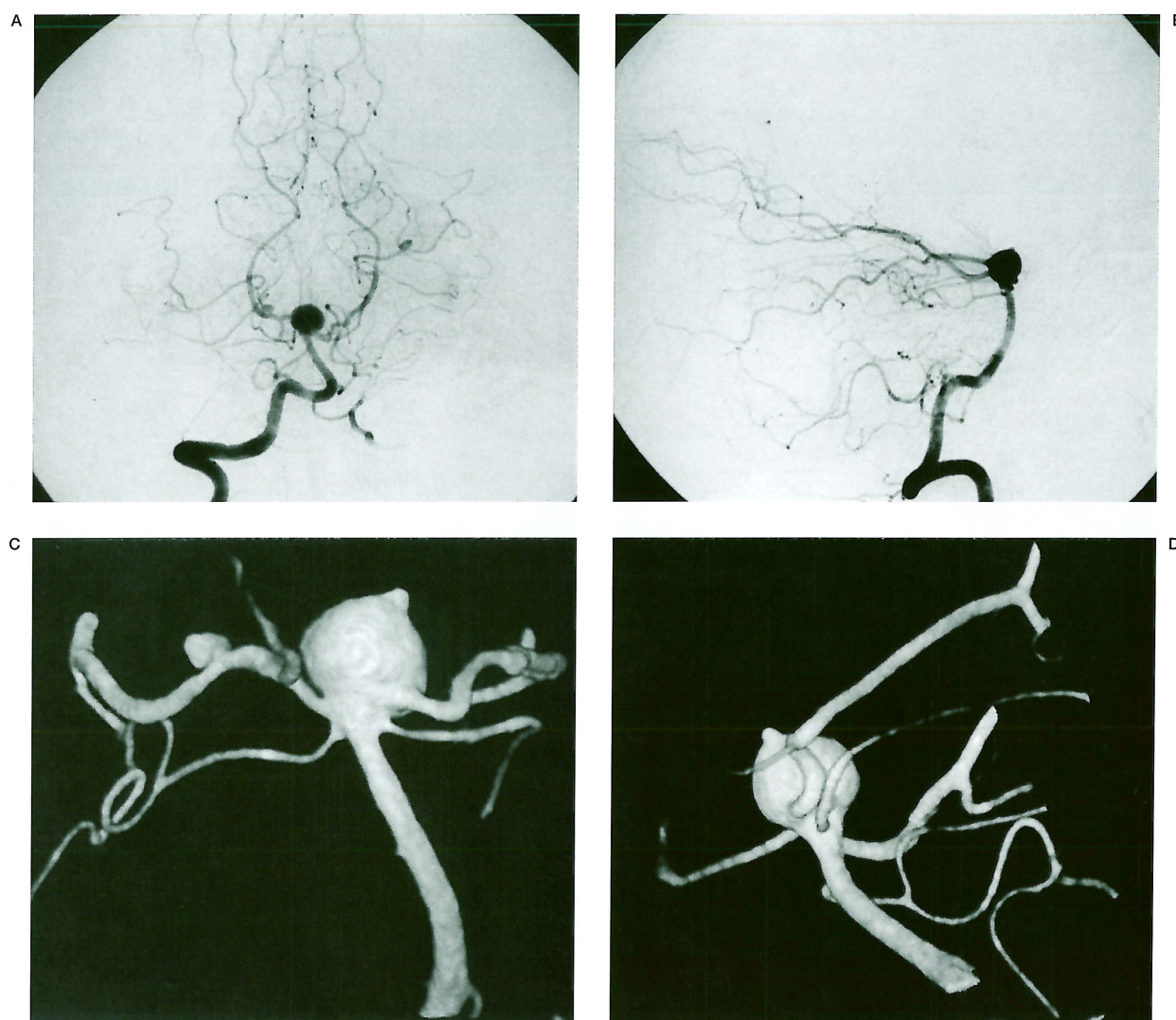
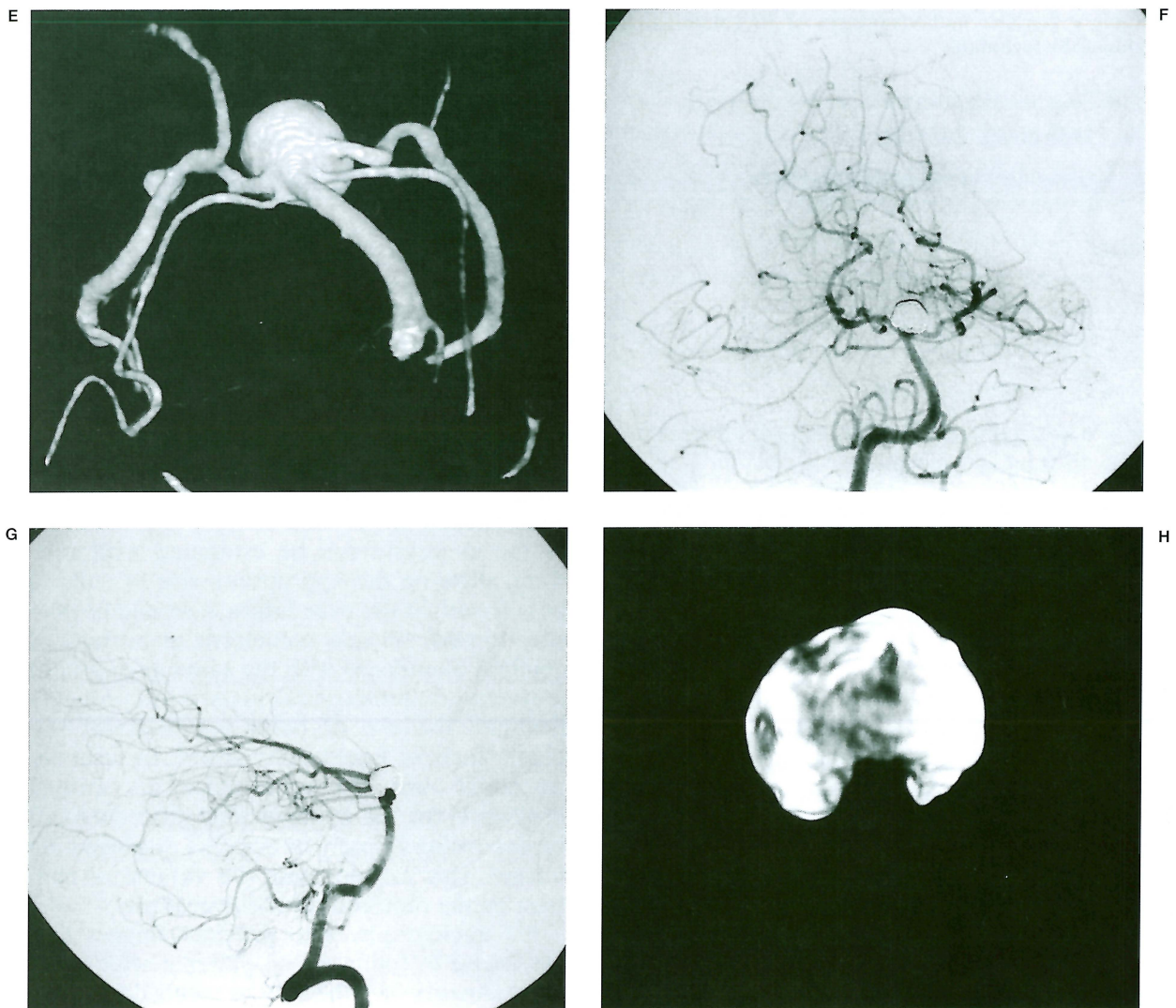


Figure 3 Case 3: AP and lateral DSA views of a large basilar bifurcation aneurysm that had bled 3 weeks previously (A and B); 3D reconstruction of the aneurysm with anterior, oblique lateral, and anterior inferior views (C,D and E); post-embolization AP and lateral DSA views (F and G); lateral view of 3D reconstruction of the GDC construct in the aneurysm (H) -

sufficient vessel opacification by contrast media. CT angiography unfortunately does not provide sufficient image definition, and MRA is sometimes impractical in acutely ill patients. Also, there is a relatively high risk of false negative examination with MRA when the aneurysm is small⁷.

Digital rotational angiography was developed to overcome some of these problems⁴. Several reports have confirmed its superiority to conventional DSA in terms of definition of the aneurysmal neck and fundus^{6,13,14}. In 1996, Turjman et al¹⁵ reported that 3D angiography provides for even better pretherapeutic evalua-

tion of intracranial aneurysms. More recently, Heautot et al⁵ reached a similar conclusion. Although we do not have quantitative data to comment on this conclusion, we think that the images speak for themselves. For example, our case 2 demonstrates that a small aneurysm on the inferoposterior wall of the M1 segment of right MCA was only clearly visible on the 3D reconstruction (figure 2C). Another case in this series, mentioned above, might have undergone unnecessary surgery in another center if the 3D study had not revealed that what was thought to be an ACom aneurysm was indeed a buckle in a normal artery.



note the groove in the base of the mass, a remodelling of the top of the basilar and both proximal P1s as a result of the balloon that was deployed. The pretreatment 3D images were helpful in determining the neck morphology and choosing the angle of attack for the application of the remodelling balloon in this case.

In a study of 260 3D examinations, mostly for aneurysm, Anxionnat et al¹ identified many advantages of 3D angiography for endovascular treatment. Our experience has also confirmed its usefulness for treatment of aneurysms, not only for the neurointerventionist, but also for the surgeon.

This technique offers spatial images that provide a better understanding of the anatomy of the aneurysm and surrounding vessels. Although CT angiography and MRA also provide 3D images that can be studied in different axes, in order to obtain a better impression for the anatomy, reconstruction times are longer and

the image resolution is not as good. As noted above, the reconstructed 3D rotational angiography images are displayed within six minutes, and the patient does not have to be transferred to another room to undergo a separate study.

Endovascular treatment for MCA aneurysms is often difficult, partly because of complicated vascular configurations. Specifically, it can be very difficult to demonstrate the neck of the aneurysm. In our case 2, the 3D angiogram provided excellent views of the neck of the aneurysm, demonstrating both M2 branches coming off the wall of the aneurysm and, consequently unsuitability for coiling (figure 2C).

Table 1 Features and advantages of 3D rotational angiography technique

- Features and advantages of 3D rotational angiography technique
- spatial demonstration of aneurysm morphology, including neck and relationship with parent and adjacent vessels
- optimal projection for endovascular treatment and follow-up
- reduces the volume of contrast media needed
- short examination time
- unnecessary to transfer the patient for other 3D study (CT, MRI)
- can be added to existing angiography system
- no artifacts from implants (e.g, clips, coils, stents) allowing post-therapeutic evaluation
- preoperative simulation for surgery

We have found that many of the MCA aneurysms that we would previously have attempted to embolise are now sent for surgery because of problematic anatomy. Indeed, we recently had a patient with a MCA aneurysm that recanalized four years after coiling because the tungsten coils dissolved, a phenomenon with these implants that is now being recognized¹⁶. When we restudied the aneurysm, the DSA was largely unchanged. The 3D reconstruction, however, demonstrated unfavorable anatomy for coiling, so she was referred for surgery.

As the anatomy around the ACom is subject to considerable variation, 3D rotational angiography is a very useful tool in this area as well. Our case 1 demonstrates the importance of having an accurate understanding of the anatomy of an ACom aneurysm. A median callosal artery was found to arise from the right posterior edge of the aneurysm neck in this case (figures 1D, 1E). This was not well appreciated on the DSA (figures 1A, 1B). In the literature, this artery was found in 27 of 206 patients with Acom aneurysms at operation, but only 11 of these could be identified easily on preoperative angiograms, and eight were not even identifiable on angiography with careful review¹².

It is sometimes beneficial for the neurosurgeon to have 3D images when planning the surgical approach to such aneurysms. In addition to providing spatial understanding of the anatomy of the lesion, the surgeon can simulate the surgical view on the screen preoperatively. With a workstation in the operating room, the 3D images can be viewed during the operation, providing better orientation for the surgeon, especially when there is complicated vascular architecture. The value of such a system for training neurosurgeons, who are now seeing fewer and fewer of these lesions, is obvious.

For the endovascular treatment of aneurysms, 3D rotational angiography is also of significant value. As demonstrated in Case 3, 3D images allow for a clear design for treatment of wide necked aneurysms. Length and diameter of the aneurysm can be estimated with software, allowing the appropriate size of coils to be selected. In the near future, it should be possible to perform easy volumetric assessment of cerebral aneurysms with the same angiographic system³. Volumetric calculation will probably facilitate the use of other endovascular implants such as liquid polymers^{9,10}, to treat intracranial berry aneurysms. Also, the optimal projection for the endovascular procedure can be determined simply by rotating displayed 3D images. This can decrease the volume of contrast media required for the procedure.

3D angiography also provides images that are useful in following-up patients after treatment. Aneurysm clips, coils or stents do not disturb the 3D images, allowing the necessary information to be obtained on the neck of the aneurysm or remnant space (figures 4A-C). 3D image of embolised material alone can be useful to monitor the deformation of material in the course of follow-up (figures 3H, 4D). We summarize the features and advantages of 3D rotational angiography in table 1.

Conclusions

High quality 3D reconstructions of cerebrovascular architecture can now be quickly obtained from images acquired during rotational angiography.

The images, easily manipulated on the computer workstation, provide valuable information for the neurointerventionist or surgeon regarding choice and execution of treatment. As

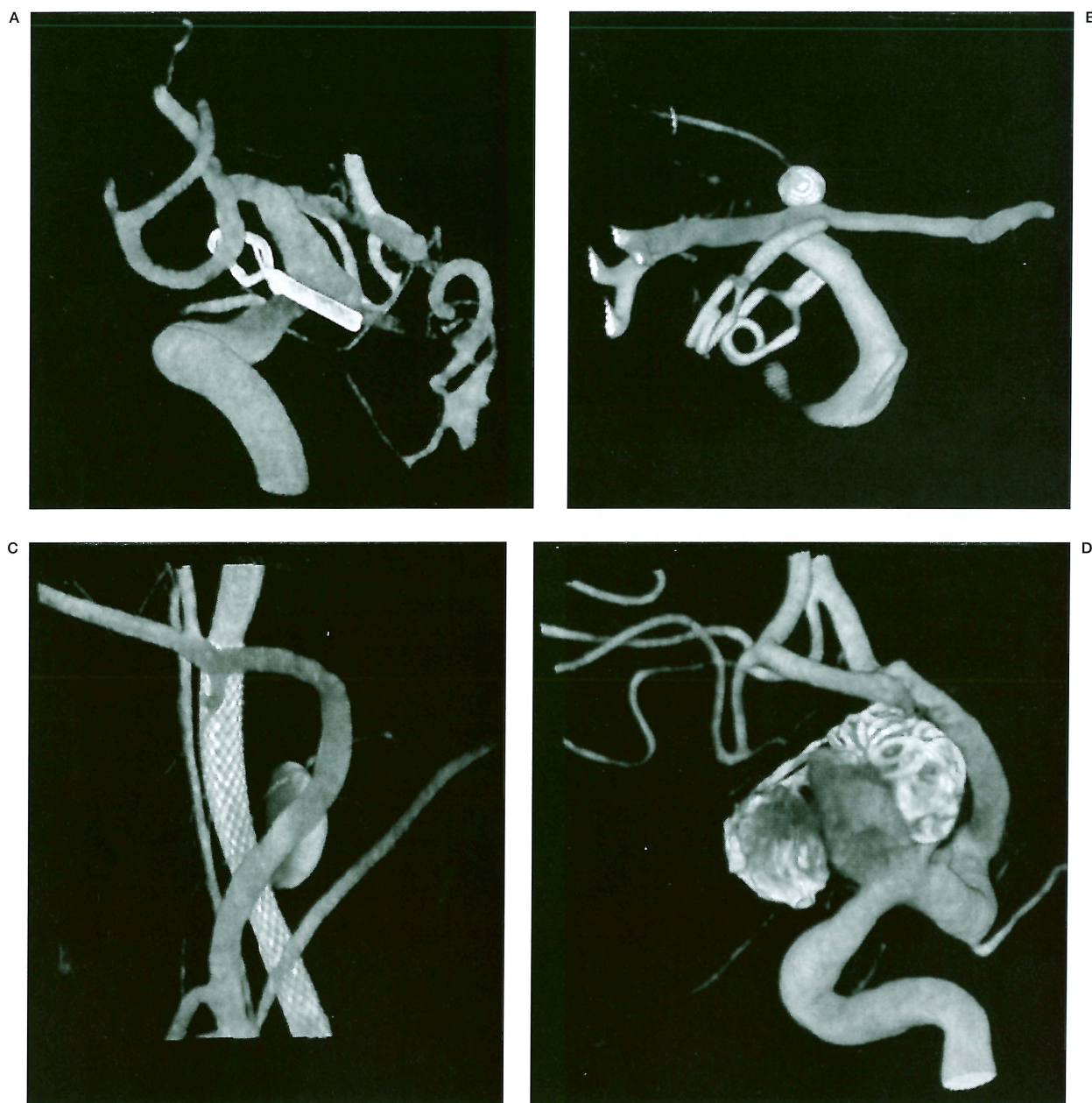


Figure 4 As no artifacts are created by metallic objects, 3D angiography allows for accurate assessment of the relevant vasculature following treatment: 3D image of the left ICA following clipping of a PCom aneurysm (A); 3D image of a coiled left ICA bifurcation aneurysm with two previously clipped ICA aneurysms (B); 3D image of a stent placed in the ICA for treatment of a dissecting aneurysm (C); 3D image of a partially recanalized (arrow), previously coiled right ICA aneurysm (D).

there are no artifacts from metallic objects, this system allows for accurate assessment of relevant vasculature following treatment.

Given these factors, high resolution 3D angiographic reconstruction should be regarded as a welcome addition to the armamentarium of those who treat cerebral aneurysms.

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